FUOYE Journal of Engineering and Technology, Volume 2, Issue 2, September 2017 ISSN: 2579-0625 (Online), 2579-0617 (Paper)

Variations of Density and Compressive Strength Before and After Charring of Some Selected Construction Timber Species of Southwestern Nigeria

[1*]Oluwaseun A. Adetayo and [2]Bamidele I. O. Dahunsi

[1]Department of Civil Engineering, Federal University Oye Ekiti, Nigeria

[2]Department of Civil and Environmental Engineering, University of Ibadan, Nigeria

oluwaseun.adetayo@fuoye.edu.ng | bio.dahunsi@mail.ui.edu.ng

Abstract - This study aimed to evaluate the percentage variations of density and compressive strength of some selected timber species mostly used for constructional purposes in Southwestern Nigeria after undergoing fire exposure. The species are: Terminalia superba (Afara), Milicia excelsa (Iroko), Nauclea diderrichii (Opepe), Khaya ivorensis (Mahogany), Mansonia altissima (Mansonia), Tectona grandis (Teak). The densities and the compressive strengths of the species were determined at Moisture Contents (MC) of 9.0, 12.0, and 15.0%. Nine specimen per species, were exposed to fire at various temperature ranges. The results of analysis by variance revealed that at 9% MC, Mahogany had the lowest density value of 439±10.58Kg/m³. At 12 and 15% MC, Afara had the lowest density values of 444±4.18Kg/m³ and 469±7.07Kg/m³ respectively. At 9, 12 and 15% MC, Opepe had the highest density values of 630±28.85Kg/m³, 686±22.64Kg/m³ and 752±17.22Kg/m³ respectively. Afara of 9, 12 and 15% MC had the lowest compressive strength parallel to the grain values of 9.59±1.08N/mm2, 9.59±1.08N/mm2 and 8.13±1.01N/mm2 respectively, while Mahogany had the highest compressive strength parallel to the grain values of 16.57±0.50N/mm2, 15.17±0.49N/mm2 and 12.12±0.42N/mm2 at the three MC levels. Post fire exposure revealed that Afara had the highest percentage change in density and compression in parallel values, while both Iroko and Mahogany exhibited the lowest percentage change in density and compression in parallel values. This study indicated that Mahogany and Iroko species which had lowest post fire change in density and compression in parallel values are useful and recommended to ensure the safety in case of fire outbreaks.

Keywords: Nigeria timbers, constructional purpose, wood density, compressive strength

1 Introduction

Many buildings and civil engineering works are at high risk of fire. Therefore, accurate prediction of behaviour of the structures subjected to fire is of primary importance for the evacuation of persons, as well as for the safety of rescue teams. (Bednarek, 2008). The history and development of timber structures is an extensive topic. Timber has been used in the construction of buildings, bridges, machinery, war engines, civil engineering works and boats, etc., since mankind first learnt to fashion tools (Kuklik, 2008). Until recently, the use of timber for major structures was viewed with suspicion, or at best accepted as a black art, practiced by a few privileged professionals.

However during the past two decades, some very useful analytical tools have been developed, which enable the reliability of timber structures to be compared with the reliability of constructions with other structural materials such as steel and reinforced concrete. As a result, timber is now viewed as a respectable construction material. Heavy wood members have long been recognized for their ability to maintain construction integrity while exposed to fire. Early mill construction from the 19th century utilized massive timbers to carry large loads and to resist structural failure from fire. Wood density is an important wood property for both solid wood and fibre products in both conifers and hardwoods (De Guth, 1980).

* Corresponding Author

Panshin and de Zeeuw (1980) reported that density is a general indicator of cell size and is a good predictor of strength, stiffness, ease of drying, machining, hardness and various paper making properties. Brazier and Howell (1979) also expressed the opinion that density is one of the most important properties influencing the use of a timber. They emphasized that it affects the technical performance of wood and in particular the strength and processing behaviour of sawn wood and veneer, and the yields of wood fibre in pulp production. Cown (1992) reported that the density of wood is recognised as the key factor influencing wood strength. Indeed according to Schniewind (1989) much of the variation in wood strength, both between and within species, can be attributed to differences in wood density.

Research has shown that higher density species tend to have stronger timber than lower density species (Addis Tsehaye et al., 1995; Walker & Butterfield, 1996). The mechanical properties of wood are dependent on the density, moisture content, the amount of extractives, among other factors (Chrsitoforo et al., 2012), strength of wood increases as the wood density increases. When evaluating the density of wood, the level of moisture in which its mass and volume were measured must always be known. Mechanical properties most commonly measured and represented as "Strength properties" for design include maximum stress in compression parallel to grain, compressive stress perpendicular to grain. The study aimed to investigate the change in post fire density and compression in parallel of the selected timber species at their corresponding moisture contents.

2 Materials

Preliminary studies were carried out to identify timber species used in the construction of structural members in South-western Nigeria. Six structural timber species were taken out of the ten mostly available species. All timber samples used in this research were taken from the heartwood region of the individual tree. And they were specially ordered from the lumber market. The six species were: Afara (Terminalia superba), Iroko (Milicia excelsa), Mahogany (Khaya ivorensis), Mansonia (Mansonia altissima), Opepe (Nauclea diderrichii) and Teak (Tectona grandis)

3 Experimental Methodology

3.1 Determination of Density and Moisture Content

The specimens were cut into dimensions of 60mm x 20mm x 20mm for density and moisture content determination. (Plates 1.1 and 1.2). Five samples were taken for each species and tested. The average results were then determined. Densities were determined by dividing the mass of the specimen by the volume as per equation 1.

$$Density\ \rho, = \frac{m}{v} \qquad (1)$$

where m = the mass in gram, obtained from weighing directly using digital weighing balance (Plate 1.2), and v = the specimen volume, determined by multiplying (60 x 20 x 20) mm^3. Corresponding value of density for each specimen was converted to kilogram cubic meter (kg/m^3). Density is moisture dependent, because moisture adds to the mass and may cause volume to swell. Moisture content is defined as the ratio of the mass of removable water (mwater) to the dry mass of wood (mdry). The dry mass is obtained by oven drying at 103 ± 2 °C for 24hours as per ASTM D143-94. Moisture content can be expressed as a fraction or in percentage terms (Equation 2)

$$Moisture\ Content\ (MC) = \frac{m_{wet} - m_{dry}}{m_{dry}}\ (100\%) \qquad (2)$$

Specific gravity is a measure of the relative amount of solid cell wall materials and extractives in the cell lumen of a piece of wood. It is also known as the relative density or density index. It has been found to be the best single index of the quality and the strength of wood (Nicholls, 1984).

Plate 1.1: Extraction of samples using horizontal plain saw

Plate 1.2: Sample on a weighing balance

3.2 Compression parallel and perpendicular to the grain

This test deals with obtaining the maximum crushing strength of the wood sample. The samples sizes is 60mm x 20mm x 20mm (Plate 1.3) and the load of 1tonne (approximately 10000N or 10KN) was applied to the piston of the cage at a rate of 0.01mm/s (Plate 1.4). One of the precautions necessary in evaluating this property is the need to ensure that the samples do not buckle during loading, thereby subjecting it to a bending rather than a compressive stress. A special cage which ensures a uniform distribution of load over the cross-section was used. The compressive strength in (N/mm2) was obtained by:

$$Compression = \frac{P}{Area} \qquad (3)$$

P = load in Newton (N); Area = L x b; L = Length in mm; b= thickness in mm

The mean samples for each species were calculated and recorded

Plate 1.3: Samples of standard size (60mm x 20mm x 20mm) on display

Plate 1.4: Hatt turner Compression Tester

4 Results and Discussion

4.1 Density and Moisture Content

Table 1 showed the mean densities of each species specimen at their corresponding Moisture Contents (MC) 9, 12 and 15%. The results showed that as timber species moisture content increases, the density increases. At 9% MC, Mahogany had the lowest density value of 439 ± 10.58 Kg/m³. At 12 and 15% MC, Afara had the lowest density values of 444 ± 4.18 Kg/m³ and 469 ± 7.07 Kg/m³ respectively. At 9, 12 and 15% MC, Opepe had the highest density values of 630 ± 28.85 Kg/m³, 686 ± 22.64 Kg/m³ and 752 ± 17.22 Kg/m³ respectively.

Table 1: Density and their corresponding Moisture Content (MC)

Species	MC (%)	Mean Density (Kg/m3)	Standard Deviation
Afara	9	444.00	3.24
	12	444.00	4.18
	15	469.00	7.07
Iroko	9	532.00	20.83
	12	544.00	9.95
	15	614.00	6.63
Mahogany	9	439.00	10.58
	12	451.00	6.20
	15	521.00	15.22
Mansonia	9	566.00	16.43
	12	580.00	9.20
	15	591.00	7.31
Opepe	9	630.00	28.85
	12	686.00	22.64
	15	752.00	17.22
Teak	9	505.00	2.92
	12	569.00	3.96
	15	657.00	4.53

4.2 Compression Results

The mean values of compression strength parallel to the grain at 9, 12, and 15% MC for each species are given in Table 2 Compression strength parallel to the grain is higher than perpendicular to the grain and the results are similar to previous results obtained from Odom et al., (1994) promotion of valuable hardwood plantations in the tropics and Excerpts from the rules for materials 1-Part 3 GL2003. From the results, it showed that as timber species moisture content increases, the compressive strength parallel to the grain decreases.

Afara of 9, 12 and 15% MC had the lowest Compression strength parallel to the grain values of 9.59 ± 1.08 N/mm2, 9.59 ± 1.08 N/mm2 and 8.13 ± 1.01 N/mm2 respectively, while Mahogany had the highest Compression strength parallel to the grain values of 16.57 ± 0.50 N/mm2, 15.17 ± 0.49 N/mm2 and 12.12 ± 0.42 N/mm2 at the three MC levels.

Table 2: Compression results parallel to grain and their corresponding Moisture Content (MC)

Species	MC (%)	Mean Compression (N/mm2)	Standard Deviation
Afara	9	9.59	1.08
	12	9.59	1.08
	15	8.13	1.01
Iroko	9	14.35	1.30
	12	13.05	1.29
	15	10.56	1.14
Mahogany	9	16.57	0.50
	12	15.17	0.49
	15	12.12	0.42
Mansonia	9	13.50	1.17
	12	12.08	0.95
	15	10.86	0.93
Opepe	9	16.03	2.87
	12	13.80	2.63
	15	11.59	2.40
Teak	9	14.69	0.68
	12	12.15	0.60
	15	9.52	0.52

4.3 Post Fire Strength Properties of Wood Samples

The density and compressive strength of the wood samples that had charred were tested to determine their post fire strength after 0 – 60 minutes fire exposure and temperature ranging between 20°C to 300°C inside electric furnace (Plate 1.5), the char layers were easily scrapped off. The charred portion has no residual load capacity. The wood beneath the char layer has residual load capacity, but this residual capacity is less than the load capacity prior to fire.

Plate 1.5: Specimen inside Electric Furnace during fire exposure

4.4 Post Fire Density of Samples

Tables 3 showed the post fire densities values of samples. It results showed that timber species with high densities exhibited low charring rate and those species with low densities charred more. At fire exposure time of 0 - 60 minutes, 9, 12 and 15% MC, Afara had the highest percentage change in density values of 29.2, 29.1 and 28.6% respectively. At 9% MC, Iroko had the lowest percentage change in density values of 27.3%, while at 12 and 15% MC, Mahogany had the lowest percentage change in density values of 26.8 and 25.9% respectively.

Table 3: Post Fire Density of Samples

Species	MC (%)	Mean Density Before Charring (Kg/m3)	Mean Density After Charring (Kg/m3)	Percent age Change
Afara	9	444.00	314.35	29.2%
	12	444.00	314.80	29.1%
	15	469.00	334.87	28.6%
Iroko	9	532.00	386.76	27.3%
	12	544.00	397.66	26.9%
	15	614.00	453.13	26.2%
Mahogany	9	439.00	318.71	27.4%
	12	451.00	330.13	26.8%
	15	521.00	386.06	25.9%
Mansonia	9	566.00	402.43	28.9%
	12	580.00	415.86	28.3%
	15	591.00	427.29	27.7%
Opepe	9	630.00	454.86	27.8%
	12	686.00	498.72	27.3%
	15	752.00	551.97	26.6%
Teak	9	505.00	366.13	27.5%
	12	569.20	414.94	27.1%
	15	657.00	483.55	26.4%

Table 4: Post Fire Compression results parallel to grain of Samples

Species	MC (%)	Compression (N/mm2) Before Charring test	Compression (N/mm2) After Charring test	Percentage Change
Afara	9	9.59	1.57	83.6%
	12	9.59	1.65	82.8%
	15	8.13	1.45	82.1%
Iroko	9	14.35	2.61	81.8%
	12	13.05	2.47	81.1%
	15	10.56	2.07	80.4%
Mahogany	9	16.57	2.87	82.7%
	12	15.17	2.73	82.0%
	15	12.12	2.27	81.3%
Mansonia	9	13.50	2.28	83.1%
	12	12.08	2.11	82.5%
	15	10.86	1.98	81.8%
Opepe	9	16.03	2.85	82.2%
	12	13.80	2.52	81.7%
	15	11.59	2.21	80.9%
Teak	9	14.69	2.57	82.5%
	12	12.15	2.21	81.8%
	15	9.52	1.80	81.1%

4.5 Post Fire Compression Results

Table 4 showed the post fire Compression parallel to grain values of samples. At fire exposure time of 0 - 60 minutes, 9, 12 and 15% MC, Afara had the highest percentage change in compression parallel to grain values of 83.6 and 82 and 82.1% respectively. At 9, 12 and 15% MC, Iroko had the lowest compression parallel to grain value of 81.8, 81.1 and 80.4% respectively.

5 Conclusion

From the results of the study on the effect of fire on the constructional timber species, it can be concluded that density and moisture content are of great importance properties of wood, as the moisture content increases, the wood density also increases, wood with higher density exhibited higher resistance to fire. Similarly wood with higher density possessed higher compressive strength and ultimately showed lower charring rate. Mahogany and Iroko species which exhibited lowest post fire change in density and compression in parallel values recommended useful to ensure the safety in case of fire outbreaks.

6 References

ASTM D 143-94. (2006). Standard Methods of Testing Small Clear Specimen of Timber. American Society for Testing and Materials, USA.

Addis Tsehaye, A.H., Buchanan, A.H., &Walker, J.C.F., (1995). A Comparison of Density and Stiffness for Predicting Wood Quality. Journal of the Institute of Wood Science 13(6):pp.539-543.

Bednarek, Z., (2008). Influence of Strength Reduction of Tmber in Fire on Structural Resistance. Research Gate.

Brazier, J.D., & Howell, R.S., (1979). The use of a breast height core for estimating selected whole tree properties of Sitka spruce. Forestry. 52(2): pp. 177-185.

Christoforo, A.L., Rocco, F.A.L., Morales, E.A.M., Panzera, T.H., (2012). Influence of Displacements of Calculus of Longitudinal Modulus of Elasticity of Pinus Caribaea Structural Round Timber Beams. International Journal of Agriculture and Forestry, v.2, pp.157-160

Cown, D.J., (1992). Corewood (Juvenile Wood) in Pinusradiata-Should we be Concerned? New Zealand J. Forestry Sci. 22(1): pp. 87-95.

De Guth, E.B., (1980). Relationship between Wood Density and Tree Diameter in Pinuselliottii of Misiones Argentina. IUFRO Conf. Div. 5 Oxford, England. 1p (Summary).

Kuklik, P., (2008). Handbook 1 Timber Structure. Leonardo da Vinci Pilot Project. Educational Materials for Designing and Testing of Timber Structures 1:pp.1-13

Nicholls, J.W.P., (1984). Tracheid cell dimension and density relationships for normal and abnormal wood of Pinus radiata D. Don. Australian Forest Research 14(2): 8589

Odom E.M., D.M. Blackketer and B.R. Suratno. 1994. Experimental and Analytical Investigation of the Modified Wyoming Shear-test fixture. Experimental Mechanics. 34(1): 10-15

Panshin, A.J., & de Zeeuw C., (1980). Textbook of Wood Technology, 4th Edition. McGraw-Hill Book Co. New York. pp.722.

Schniewind, A.P., (1989). Concise Encyclopaedia of Wood and Wood-based Materials. Pergamon Press. pp. 248.

Walker, J.C.F. and Butterfield, B.G. (1996). The Importance of the Microfibril Angle forthe processing industries. New Zealand Forestry.